Lightning and emp protection of amateur radio equipment

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THERE IS a growing interest in the protection of communication equipment and systems against lightning and electromagnetic pulse (emp) radiation. This is especially of interest for emergency communication antenna installations for Raynet and repeaters, which may be located on high buildings, and therefore need positive protection against lightning and other static discharges.

The incidence of thunderstorms varies widely over the country, and from year to year. It is an old wives' tale that "lightning never strikes in the same place twice". Any building or antenna mast in an exposed position is always a potential target. A map showing the areas of the country in terms of the average number of thunderstorm days is given in Fig 1. Fig 2 is a map of England and Wales showing the resistivity of the ground. Both maps have been produced from data obtained by the Electrical Research Association from their surveys.

There can be little doubt that the greatest risks arise in areas of poor ground conductivity. This has been shown by faults in the telephone circuits

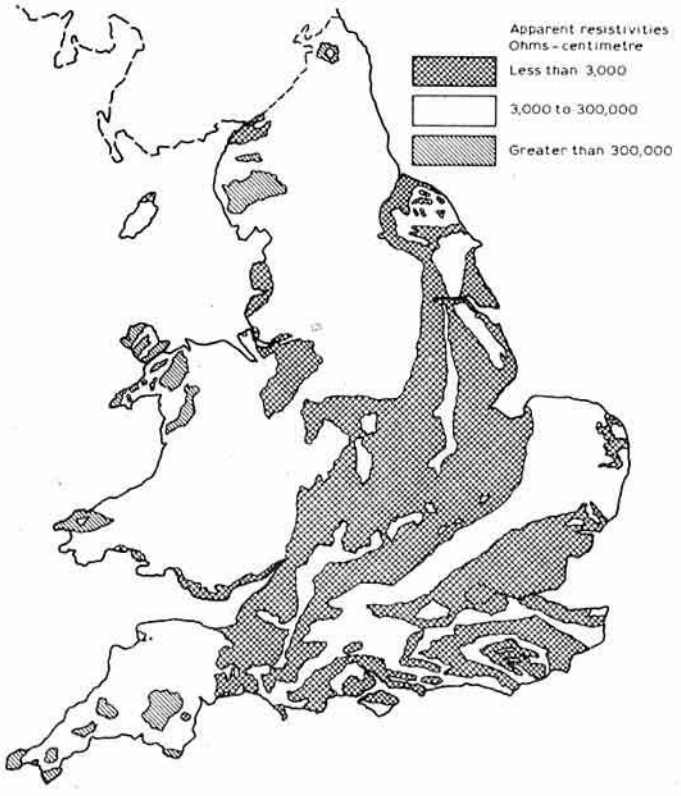
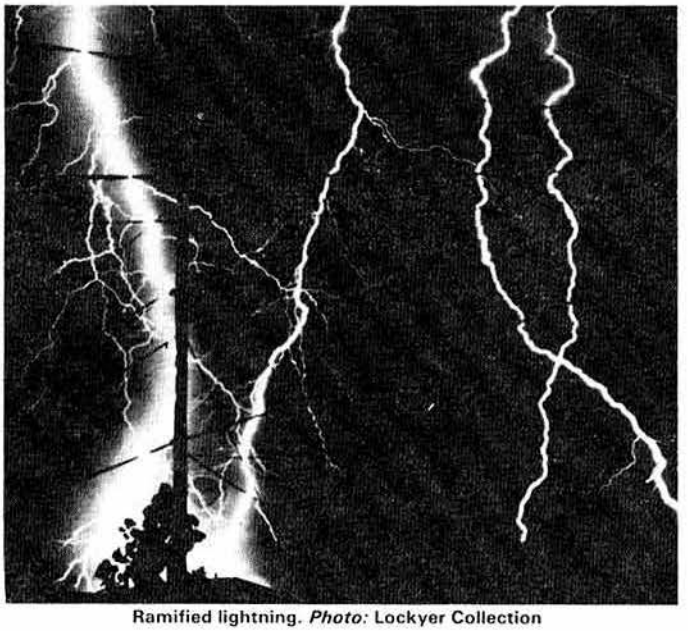


Fig. 1. Resistivity map of England and Wales



Ramified lightning. *Photo:* Lockyer Collection

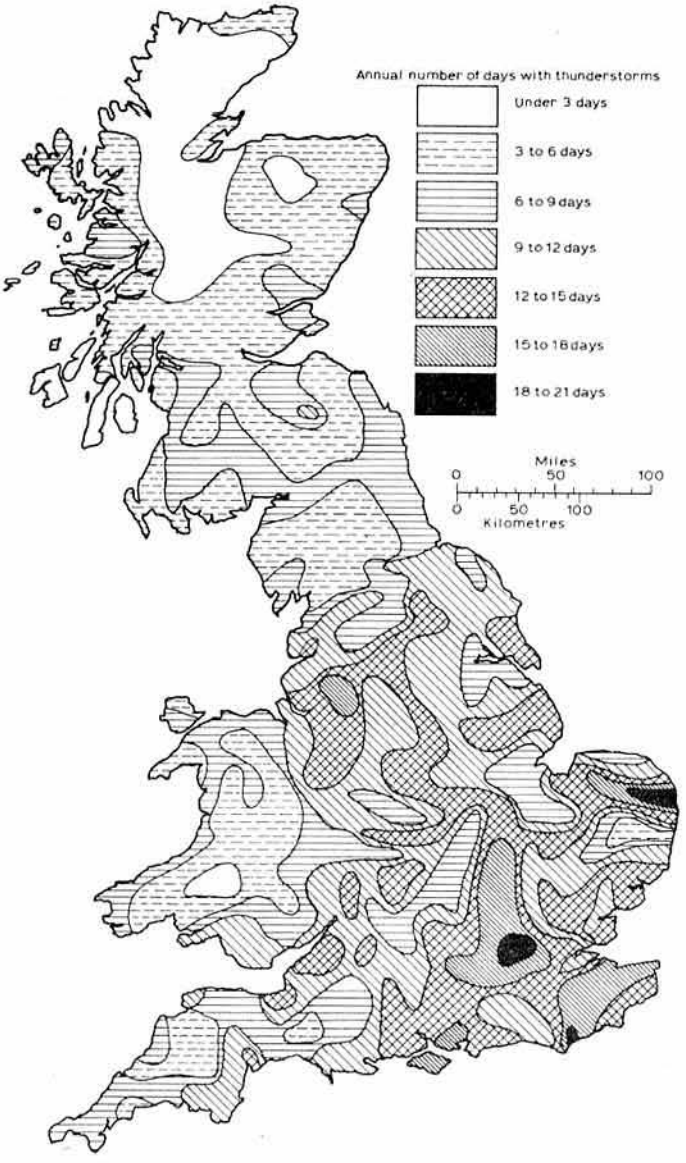


Fig 2. Average annual number of thunderstorm days in England, Scotland and Wales

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of new exchanges in such areas in recent years. The use of gas-filled protectors (type 14A) has overcome the problem at the exchange end of the circuits, and similar devices (Type 11A) are being fitted at the customers' terminations.

In areas where both high ground resistivity and high storm frequency exist, and particularly at fairly high locations, significant failures of semiconductors can be expected. Although the UK is relatively free from storms of any great severity, occasionally one of tropical proportions does occur, with consequent damage. Protection against direct lightning strikes is virtually impossible. However, much serious damage can be caused by nearby strikes, which induce severe surges in cables and overhead lines of supply mains. Switching surges caused by interruption of the supply mains often produced by lightning strikes on the grid-system in a different area can also cause significant damage. The most likely mains-borne damage for amateurs is usually to the power supply rectifier diodes in the first instance; and progressing further into the equipment with increasing surge levels, data processors are at risk unless adequate protection is provided.

Protection should therefore be considered both for the antenna installation and the mains input to the equipment. This is more important for semiconductor than for valve equipment. Surges in the mains supply are all too often neglected when in fact this may be the most likely source of damage other than by a direct strike.

Static

The static electric field near the ground under conditions of stable fine weather is usually in the region of 100V/m. However, in the vicinity of thunderclouds this is likely to rise to several kilovolts/metre. Under these conditions it is not unknown for a man's hair to stand on end!

Development of static sometimes results in a single very violent local discharge without a storm developing. During heavy rain (or hail) there is a considerable increase in random noise due to the static charge which accumulates while it falls through the atmosphere. This will charge-up a wire antenna to quite a high voltage, and unless there is some adequate path to earth it could damage the input stage of a semiconductor receiver or other equipment.

Protection devices

There have been many types of device offered for the protection of equipment, such as special resistors (carbon blocks) or semiconductors of one type or another, but by far the most satisfactory device so far developed is the gas-filled surge arrester.

This device is the only type which will hold the voltage down to a low and constant value under wide ranges of fault current. It will maintain a voltage of the order of 20–40V when currents of 5,000A and above are present, without self-destruction. The various forms were primarily designed for the protection of telephone lines, which at the time were mostly overhead wires.

Initially these surge arresters were glass-enclosed single-gap (two-electrode) types such as the AEI type 15. More recently the three-electrode metal-ceramic types such as the type 16 etc have been introduced. These have the great advantage that when one of the three gaps fires, the gas in the tube is ionized and all the gaps come into action: the separate single-gaps need to be fired individually. For single-wire (long wire) antennas, only a single-gap device is needed, Fig 3(a), while the arrangement for twin-wire feeders is shown in Fig 3(b). The ground (earth) connection is most important. It should be arranged as far as possible to be directly below the antenna downlead—it should be remembered that lightning will not go round corners! Suitable ground connections consisting of pointed copper rods

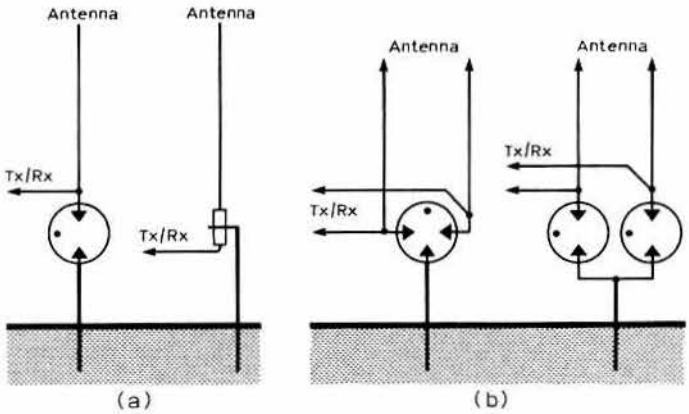


Fig 3. Antenna protection: (a) single lines; (b) twin lines

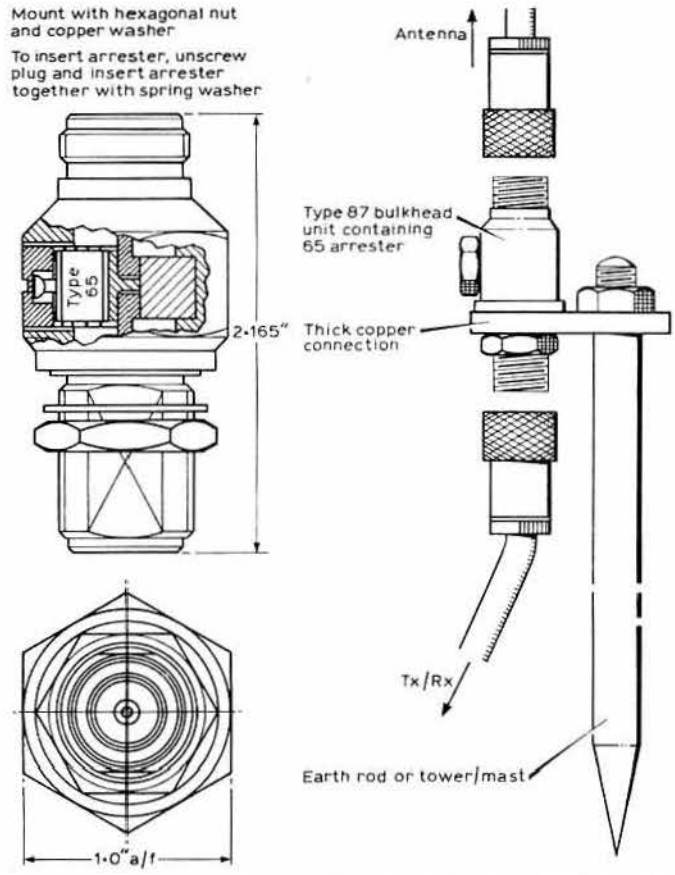
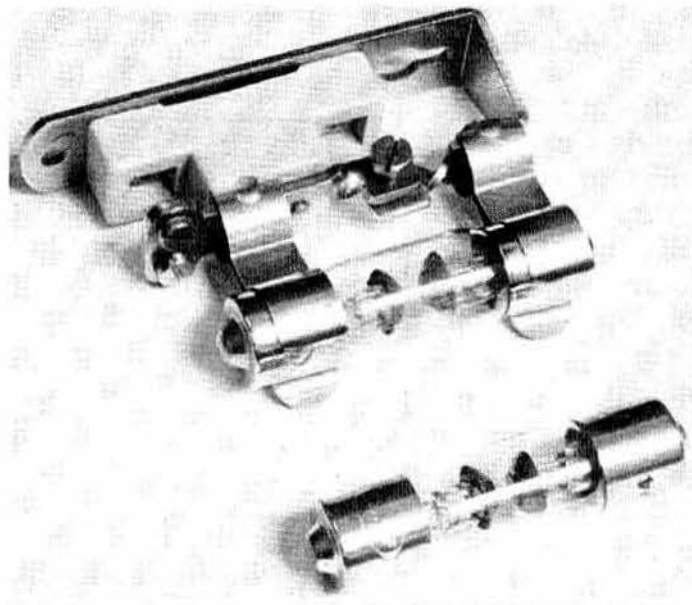

Mount with hexagonal nut and copper washer
To insert arrester, unscrew plug and insert arrester together with spring washer
Type 65
2·165"
1·0" a/f
Antenna
Type 87 bulkhead unit containing 65 arrester
Thick copper connection
Tx/Rx
Earth rod or tower/mast

Fig 4. General arrangement for use of a bulkhead fitting in an antenna feeder

(spikes) are available, supplied either with threaded ends with couplers, or plain. To ensure an adequate contact, such rods should be driven several feet into the ground. The use of domestic water pipes is not recommended because many may contain plastic pipe connections.

In the case of twin-wire feeders the three-electrode surge arrester would be more suitable for lightning and other static discharge protection. There are several types available, together with appropriate holders. For a twin feeder system, only two single-gap devices are necessary, one for each wire, as shown in Fig 3(b), which also shows typical circuit arrangements. For coaxial line protection against lightning and emp radiation, an arrangement using a fast-operating device, such as the type 65, is shown in Fig 4.

For those who like to "see" what is happening, an earlier (though



Early glass-enclosed surge arrester type 15 with holder, including an external adjustable spark gap

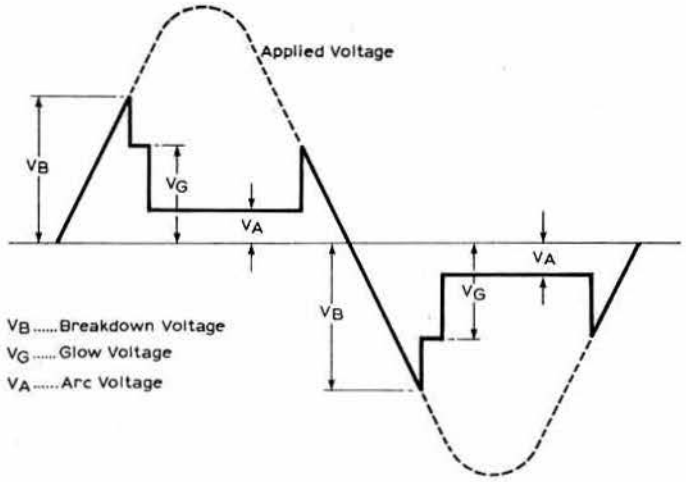
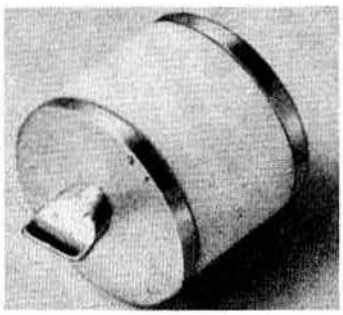


Fig 5. Voltage characteristics of a gas-filled surge arrester

obsolete and less-effective) device, the AEI type 15 glass-enclosed gas-filled surge arrester, is suitable. (The type 15 is obsolete but may be found as surplus from time to time.) When mounted in its proper holder, with an adjustable parallel spark gap included, it is very effective. With this type of device the flashes can be observed by the glow in the tube, so that operation of the station can continue until such time as it becomes obviously dangerous, shown by virtually continuous flashing of the arrester.

For some applications it is desirable that some form of fail-safe feature is provided for the gas-filled surge arrester. This is usually needed for the protection of the mains supply lines rather than antennas. Depending on the application, the fail-safe device must be suitable for the service; it can be either fail to open circuit or fail to short circuit. For example, on a signal circuit, failure needs to be to open circuit otherwise the whole system would shut down until a replacement had been installed. Fail to short circuit is normally suitable for cases such as domestic services or where regular maintenance personnel are readily available. Protector type 16B is a fail to short circuit, while type 160 is an encapsulated unit that fails to open circuit.



Type 65 surge arrester. Diameter 8mm, length 6·5mm, surge current 5,000A, striking time 1·5-2ns

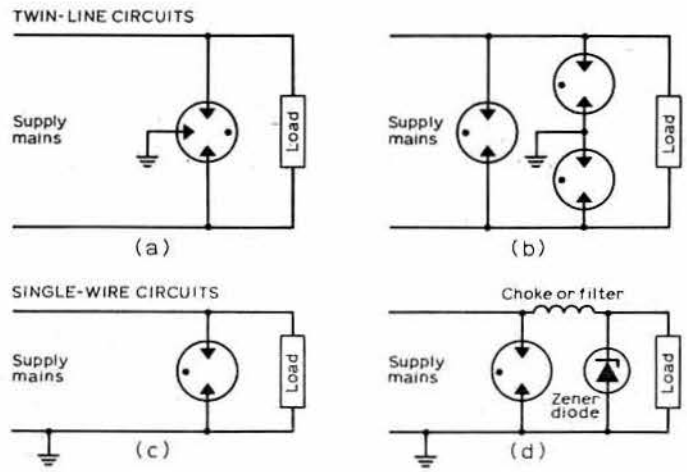


Fig 6. General circuit connections. (a) Three-electrode surge arrester. (b) Three two-electrode arrester equivalent to one three-electrode arrester. (c) General single-wire circuit with a two-electrode arrester. (d) Arrangement suitable for low-voltage or sensitive equipment zener diode voltage limiter

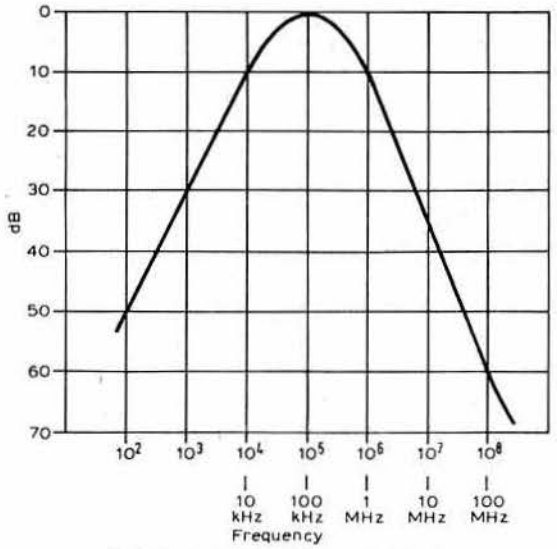


Fig 7. Typical emp radiation distribution

Earthing switches

With properly-installed gas-filled surge arresters and their large fault current capability, there is little value in having an earthing switch unless it is of adequate conductor size and installed directly in line with the earth path. If one is used, it should at least be installed outside the building.

Voltage characteristics of gas-filled surge arresters

The voltage characteristic is illustrated in Fig 5. This shows that when the voltage across the device reaches a certain value, the gas ionizes (striking voltage, Vs), and if this or larger voltage is maintained, it rapidly falls to a lower voltage (glow voltage, Vg), and as the current through the device continues to increase it falls to a still lower voltage (arc voltage, Varc). This voltage is maintained until the applied voltage falls to the glow voltage, then when the glow is extinguished the current through the device falls to zero again.

The striking voltage of the device to be used must be selected so that under normal conditions the voltage applied to it does not cause it to strike. Gas-filled surge arresters are normally selected for a narrow range of striking voltages, usually less than 2:1: for example, 150–250V.

Electromagnetic pulse (emp) protection

Protection of antennas, electronic equipment and supply cables requires very fast-operating devices that have a low "clamp" voltage (arc voltage) irrespective of the level of fault current, which will fire in 1 or 2ns. The spectrum of emp radiation covers a wide frequency range, having a peak centred on approximately 100kHz. The curve given in Fig 7 illustrates the distribution of typical radiation. The vulnerability of various electronic components is shown in Fig 8, from which it can be seen that it would take 100 times greater energy to damage a valve than a transistor, and 10,000 times more than would damage an integrated circuit. Erasure of computer memory will occur at even lower levels of radiation.

A suitable gas-filled device, type 65, is available in two through-line forms. Type 73, for insertion in a feeder cable, provides a discharge path (shunt)

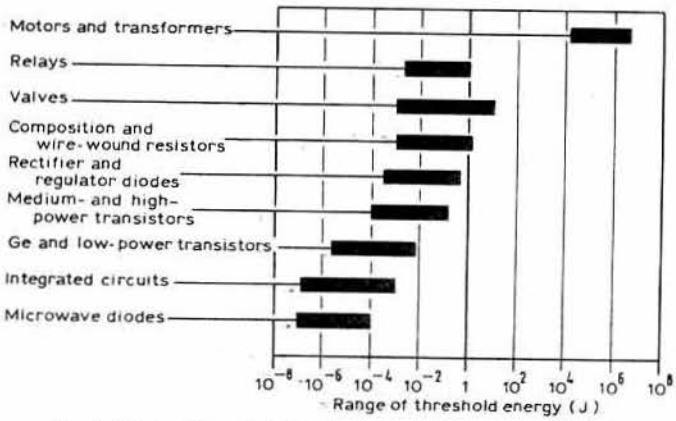
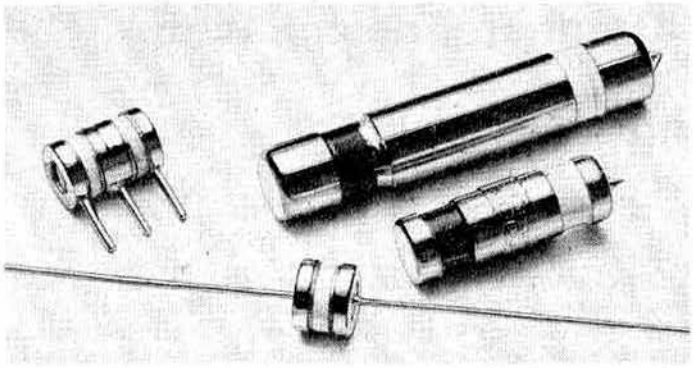


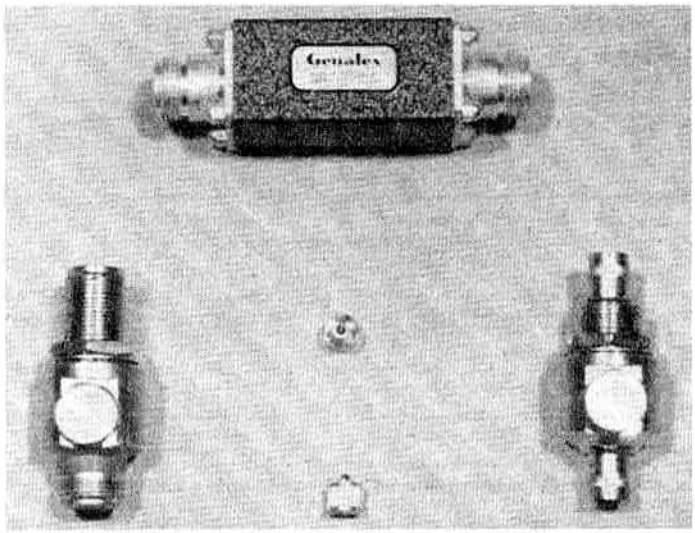
Fig. 8. Vulnerability of electronic components to emp radiation



Metal ceramic surge arresters. ***Top, l to r:*** **type 49A (PO14A) three-electrode; type 16 three-electrode.** ***Centre right:*** **type 21 three-electrode.** ***Foreground:*** **type PO11A two-electrode**

between the inner and the outer of the coaxial cable. Type 87 is similar but made for bulkhead mounting. The first can be supplied with type N, uhf or bnc connectors. This unit introduces little more discontinuity than that caused by a pair of connectors alone—a maximum vswr of 1:1 at f. 400MHz, with a capacitance of 4pF. The power-handling capacity with a type 65 of a minimum striking voltage of 150V will allow a maximum rf voltage of 100V rms on the feeder line. This allows a power of 200W at a vswr of unity; with a vswr of 2:1, a power of 100W can be handled. This level is adequate for most vhf and uhf Raynet and repeater station needs.

An alternative device is a miniature pin type 72B (series) arrester in the form of a very short length of coaxial cable, 10mm long (excluding the centre conductor ends) by 2·5mm diameter, which is suitable for use at uhf.



Through-line protectors using type 65 surge arrester. ***Top:*** **type N coaxial cable type.** ***L to r:*** **type N bulkhead type 87; type 65 surge arrester; type bnc bulkhead**

Open spark gaps

Open spark gaps as a means of protection against lightning and other discharges, especially for long wire antennas, have been used by many amateurs for almost as long as radio has been an amateur activity. These can be effective provided that the actual gap is as small as possible, allowing for the normal peak voltage that will be across the gap under usual operating conditions. Sharp, pointed electrodes are less satisfactory than those with rounded ends, due to the possibilities of ionization in the gap, especially under damp atmospheric conditions.

The minimum recommended requirements are for flat (rounded edges) or round-ended electrodes of not less than 0·125in diameter (preferably larger), adjusted to a gap spacing that will occasionally "spark over" under normal operation, with a reasonably low vswr. For the average station the gap should be 0·5mm or less.

Masts and towers

At first sight a metal mast or tower may appear to be a robust structure. Mechanically they are undoubtedly satisfactory, but electrically, as a very low resistance conductor to carry the very large currents that may be encountered with a lightning strike, they are less satisfactory. Currents in excess of 10,000A pulse are likely to be involved, and the resistance needs to be of very low ohmic value. The discontinuities in the case of the crank-up type are particularly likely to have relatively high resistance at the joints. The fixed type, where the various sections are bolted together, may also be suspect.

The only safe lightning conductor is a thick wire or strip of copper or aluminium (approximately 1·5 times the size of copper) run from the top to the earth connection, preferably extending above the top of the mast or tower with a "lightning collector" at the top. Similarly, if the antenna is to be protected the treatment needs to be applied to a wooden or other non-conducting mast.

Earth connection

Provision of an adequate earth connection is most important if the tower or mast is to be protected. Towers which are supported by a post cemented into the ground will be substantially insulated from the surrounding ground by the concrete. Wall-mounted towers suffer from the same defect.

The most satisfactory earth connection consists of a rod or tube with a pointed end driven into the ground to a depth of at least 5ft, preferably more. In dry ground it may be necessary to have two or three rods which should not be closer than about 5 or 6ft to each other. In dry weather it may be advisable to water the earth with salt water.

It is worth remembering that a mast attached to or close to a building will provide protection for the building if the mast is significantly higher than the building itself, because the building will come within the cone of protection. From this point of view the higher the mast the better.

For an antenna system used on a single frequency (band), a permanent λ/4 earthed stub (known in the early days of radar as a metal insulator) may be used. The length of the stub should be cut to a λ/4 length at mid-band, the remote end being short-circuited and connected directly to earth. In the case of a coaxial cable system, the "T" junction is best made using a T-connector; suitable components are available for either type N or uhf connectors. The length of the cable is of course an electrical λ/4 and is therefore mechanically shortened by an amount depending on the particular cable used. The velocity factor will vary from 0·65 to about 0·86 depending on the dielectric.

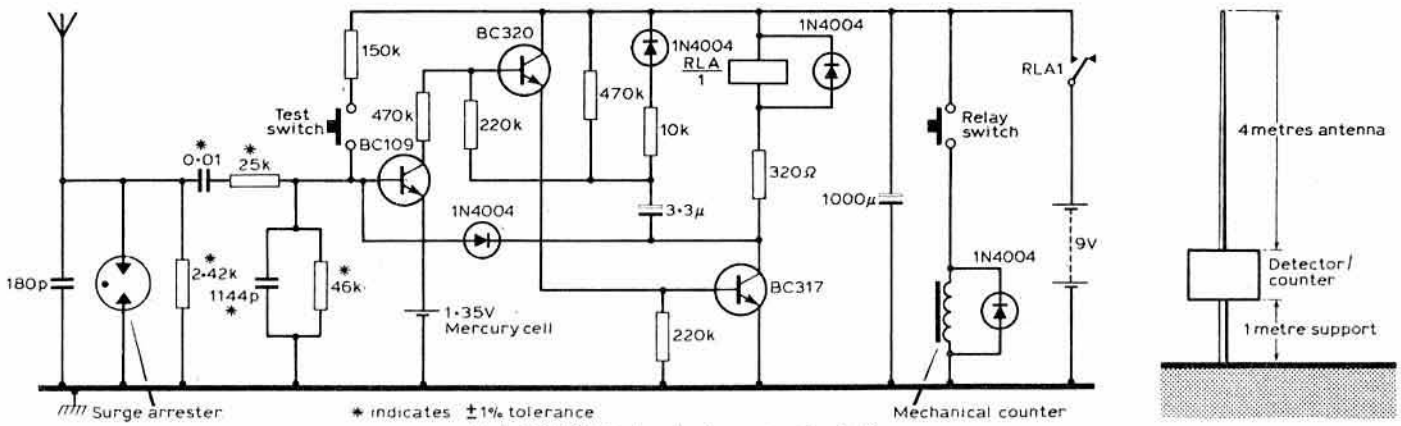


Fig 9. RSA10 lightning flash counter circuit diagram